§22. Fundamental Study of Energy Conversion Divertor for Helical Reactors

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This study intends to investigate a possible concept of divertor to utilize the high heat and particle flux load by the conversion to high grade heat. It has a tungsten armor plated on the surface of the heat sink utilizing sublimation of heat transfer media in a closed channel. Typical heat flux is 10 MW/m^2 average, and the output temperature above 500 degree C is expected.

Pulsed heat flux due to a various plasma oscillation is a typical load on divertors, and transient behavior is identified as possibly a critical issue. Temperature profile and excursion on the tungsten surface with 0.05~1MJ/ m^2 assuming ELMs in tokamaks were analyzed with ANSIS.

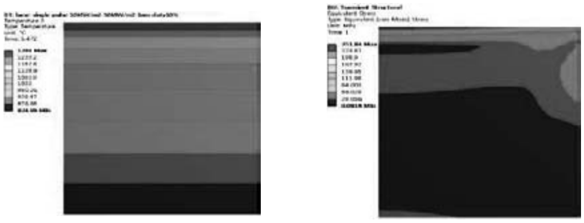

Fig. 1. Effect of pulsed heat flux of 0.13MJ/m^2 on a tungsten divertor surface, (a) temperature profile, (b) maximum stress.

Figure 1 shows a result assuming single pulse of typical ELM. Although its effect is limited in a very shallow surface area, temperature could be sufficient to cause recrystallizing or other damage even with moderate pulses that could be neglected when only average heat flux is considered. Stress due to the rapid and steep temperature gradient was found to be even more serious, particularly they are repeatedly given to cause fatigue and growth of cracking.

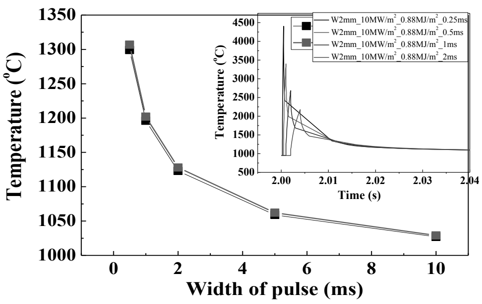

Fig. 2. Effect of pulsed heat flux as a function of pulse length.

Largest stress was observed to be compression, and both maximum temperature and stress are strongly dependent on the pulse length, as shown in the fig.2. It is known that helical systems do not show significant pulsed load on divertor such as the ones observed in tokamaks, and this feature would be one of the major advantage.

Experiments with YAG laser was performed to simulate the pulsed load on divertor. Diameter of laser is 1.2mm, and 1.1GW/m^2, 2ms pulses were irradiated on tungsten surface at the average 9.8MW/m^2 heat flux.

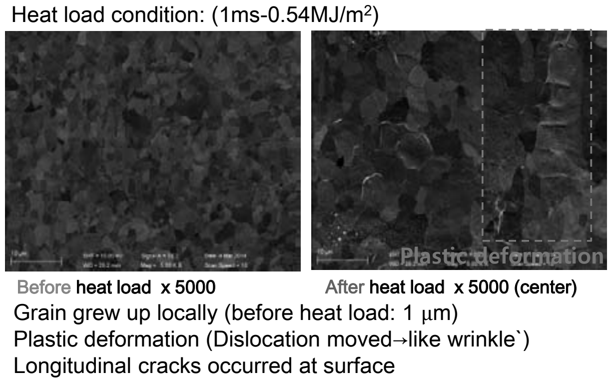

Fig. 3. Change of surface structure of tungsten by laser pulse irradiation.

Typical result is shown in the fig.3. Grain growth and plastic deformation, and crack formation was observed on the tungsten with repeated heat load within the 10MW/ m^2 range that is anticipated and supposed to be acceptable for ITER.

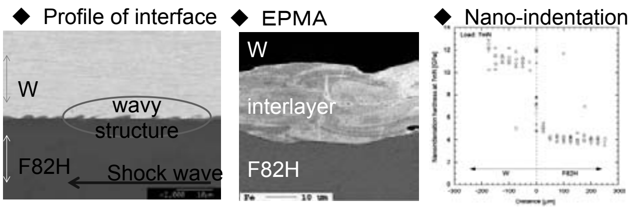

Fig. 4. Interface structure and its hardness of the explosion-welded Tungsten on F82H.

As a technique to plate the tungsten for plasma facing components, Explosive Welding under water is also investigated. This technique is already used for large scale cladding for industrial applications, and has an advantage of minimal effect of thermal excursion compared to welding or HIP. Figure 4 shows the interface profile between tungsten and F82H RAFM plated by explosion. At the left, typical wavy structure between tungsten and F82H is observed suggesting strong mechanical bonding between two materials. Middle EPMA picture indicates the formation of interlayer of tungsten and steel mixture. However the right nano-indentation hardness shows no another phases such as intermetallic compounds. These results suggest this technique could be applicable for cladding tungsten armor on divertor structure.

Under this collaborative program, heat transfer mechanism with thin structure of heat sink with thermal siphon and test of divertor component with ion beam are also performed. By integrating these studies, an attractive and innovative concept of energy converting divortor system is expected to be presented.